DEVELOPMENT OF COMPOSITE PACKAGING FILMS FROM SEAWEED HYDROCOLLOIDS

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A. THESIS TITLE

DEVELOPMENT OF COMPOSITE PACKAGING FILMS FROM SEAWEED HYDROCOLLOIDS

B. INTRODUCTION

Packaging plays an important role in the food industry, since it is responsible for, not only containing food products, but also preserve their originality, maintain quality, their appearance, convenience, and for protecting the food and providing the product information to the consumer.

The most common food packaging materials are glass, wood, metal, plastics, paper and other flexible packages such as coatings and adhesives. Synthetic plastic packaging materials are not biodegradable and consequently, they represent an environmental issue, not only because of the manufacturing process and incineration; but also due to their rapid production and waste accumulation (Raheem, 2013). Altogether, and in combination with the possible migration of non-desirable or even toxic compounds, such as additives or monomers, from the plastic to the food product, this has led to the emergence of a great social-political interest in the development of novel materials alternative to the traditional plastics, wherein biopolymers extracted from natural sources constitute a good option to obtain less contaminant and biodegradable food packaging.

Edible and ecofriendly packaging is widely categorized as films and coatings (Nair *et al.*,2007). The main difference between films and coatings is that films are stand-alone, formed separately from anything and not dependent on their intended use. Films can be used as solid covers, wraps or separation layers. On the contrary, coatings refer to the formation of a film directly over the surface of the final product, so that it becomes part of it, and it may improve or protect the final product (Gennadios, 2002).

Lately, there has been increasing research interest in the development of edible and biodegradable film components from different materials such as proteins, polysaccharides, lipids, and resins for different applications in the food processing, pharmaceutical and agricultural industries (Vieira *et al.,* 2011). Among the above mentioned materials, some of them have been extensively studied because of their relative abundance, film-forming abilities, and nutritional qualities. All these desired attributes are found in hydrocolloidal biopolymers of marine origin.

The sea has long been considered a treasure trove of a variety of protein foods, including numerous species of finfish, several species of crustaceans, molluscs and seaweeds. *Seaweed* is a colloquial term encompassing about 9000 species of macroscopic, multicellular, benthic marine algae—the plants of the sea. Growth of these algae is dependent on the presence of seawater (or at least brackish water) and the availability of sunlight sufficient to drive photosynthesis. Seaweed grows more frequently on rocky shores than on sand or shingle.

Luxuriant growth of seaweed occurs in both shallow and deep waters up to 150 m deep, as well as in estuaries and backwaters. Seaweeds are classified into four main groups on the basis of their color: red algae (Rhodophyceae), brown algae (Phaeophyceae), blue–green algae (Cyanophyceae), and green algae (Chlorophyceae). Red algae is the most abundant group (6000 species), followed by brown (2000) and green (1200).

Marine resources, apart from providing a wealth of protein foods, also provide several polysaccharides with numerous possible uses in diverse fields. Marine habitats, inhabited with diverse animals, are capable of providing interesting polysaccharides. It is likely that marine polysaccharides possess some unique properties that may be useful for effective research in the field of food technology. Although some marine polysaccharides, such as alginate, carrageenans, and agar, extracted from red and brown macroalgae, have found wide use as hydrocolloids due to their ability to form gels and function as thickeners and stabilizers in a variety of foods, the potential of many of these hydrocolloids has yet to be explored.

It is currently difficult to think about edible films as substitutes for non-edible packaging materials, but they might have complementary applications.

On the other hand, the combination of science and gastronomy in the last few years has opened the possibility of making high quality and healthy food for consumers, while optimizing the creativity to produce an innovative food design. Scientific packaging solutions could be used to solve practical problems, from an industrial point of view, but also to create food opportunities for edible films in the *nouvelle cuisine* (Arboleya *et al*., 2008).

Hence, the present study is a small footprint in the path of innovation to develop and assess the composite edible packaging films from hydrocolloids extracted from seaweeds.

C. SCOPE OF THE STUDY

Developing environment friendly food packaging film is an essential strategy and need of

the hour for a better future for an individual, the society and for the whole world. The utilization of renewable, as well as abundantly available seaweeds in the form of hydrocolloids endowed with the attributes needed in an edible film; makes it desirable for a better product outcome and usage.

D. OBJECTIVES

- Extract algal hydrocolloids from selected Seaweeds
- Formulation and Standardization of edible Films from algal hydrocolloids
- Assess the impact of crosslinking and fillers on the characteristics of the algal hydrocolloid films
- Assess the biodegradability, feasibility analyze and shelf life testing

E. METHODOLOGY

The present study was carried out in five phases.

Phase I

i. Selection of Area and Seaweeds

Coastal area**s** in the Gulf of Mannar, the first Marine Biosphere Reserve in the South and South East Asia were selected as the locale for the present study. The regions include areas running down south from Rameswaram till Kanyakumari encompassing a group of coral reefs adjoining 21 islands off the coasts in the Ramanathapuram and the Tuticorin districts as core zone and Panban in the North in Tamil Nadu, India**.** Indian Peninsula has been recorded with about 1158 species of seaweeds belonging to 271 genera comprising Red algae, Green algae, Brown algae and Blue green algae. But based on the presence of economically valuable compounds these seaweeds are widely classified as Alginophytes, Carrageenophytes and Agarophytes. Considering the ease of availability and cost-effectiveness *Sargassum cinctum* J.Agardh was selected for the present study. *Kappaphycus alvarezii* (Doty) L.M.Liao earlier known as *Eucheuma cottonii* a tropical seaweed successfully utilized by India for Seaweed Mariculture, and has been selected for the present study. *Gelidiella acerosa* is the highest contributor of agar in the Indian subcontinent (McHugh, 2003) due to its abundant availability. This prioritized *Gelidiella acerosa* (Forssk) Feldm to be utilized for the present study.

All the samples collected for the study were verified by the scientists of Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Mandapam Regional Center,

Tamilnadu, India.

The samples were identified, authenticated and certification was provided (Appendix II) by Scientist-E, Botanical Survey of India, Sothern Reginal Centre located in Tamilnadu Agricultural University, Coimbatore, India.

ii. Analysis of Nutrients

Quantitative estimation of proximate nutrients including moisture content, ash content, total carbohydrates, protein, fat and crude fiber of *Sargassum cinctum* J.Agardh, *Kappaphycus alvarezii* (Doty) L.M.Liao and *Gelidiella acerosa* (Forssk) Feldm were analyzed in triplicates using standard estimation procedures given by National Institute of Nutrition (NIN,2003). Moisture content of *S. cinctum, K. alvarezii* and *G. acerosa* were analyzed with Shimadzu Electronic Moisture Analyzer (MOC-120H). Ash content of the charred samples were estimated using muffle furnace. Total Carbohydrates were assessed with anthrone method where in, protein was estimated using Kjeldhal method. Fat content of the seaweeds were estimated by Soxhlet method using Socs plus analyzer in petroleum ether (60°C - 80°C). Crude fiber content of the seaweed was estimated using standard procedure given by National Institute of Nutrition.

iii. Analysis of Heavy Metals and Phytochemical Constituents of the Seaweeds

Heavy metal toxicity was analyzed for the hydrocolloids extracted with the selected method using Atomic Absorption Spectrophotometer (AAS). Qualitative presence of phytochemical constituents such as alkaloids, flavonoids, carbohydrates, phytosterol, protein and amino acid, phenol, saponin, tannin, terpenoid, cardiac glycoside and test for resins in aqueous and ethanol extracts of *S. cinctum, K. alvarezii* and *G. acerosa* were carried out using standard procedures. Functional compounds present in the dry powders of *S. cinctum, K. alvarezii* and *G. acerosa* seaweed samples were characterized using Shimadzu Fourier Transform Infrared Spectroscopy

iv. Analysis of Antioxidant Activity

The antioxidant activity of the aqueous extracts of *S. cinctum, K. alvarezii* and *G. acerosa* seaweed samples were measured based on the scavenging activity of the stable 1, 1-diphenyl 1- diphenyl 2-picrylhyorazyl (DPPH).

Phase II

i. Extraction of Hydrocolloids from Seaweeds- Extraction of Sodium Alginate from Alginophyte *Sargassum cinctum,* Carrageenan from Carrageenophyte *Kappaphycus alvarezii* and Agar from Agarophyte *Gelidiella acerosa*

Extraction of Sodium alginate from clean, dry powdered samples of *Sargassum cinctum* was carried out with three different extraction procedures namely SA1, SA2 and SA3. Wherein, extraction of Carrageenan from clean, dry powdered samples of *Kappaphycus alvarezii* was carried out with three different extraction procedures namely CA1, CA2 and CA3. Similarly, agar from clean, dry powdered agarophyte, *Gelidiella acerosa* was carried out with three different extraction procedures namely AG1, AG2 and AG3. The extraction methods were standardized based on the characteristics of the extracted sample and one procedure was selected for the bulk extraction process of each hydrocolloid.

ii. Characterization of the Extracted Seaweed Hydrocolloids

Characterization of the known extracted hydrocolloidal compounds such as Sodium alginate (SA1, SA2, SA3), carrageenan (CA1, CA2, CA3) and agar (AG1, AG2, AG3) from *Sargassum cinctum* J.Agardh , *Kappaphycus alvarezii* (Doty) L.M.Liao and *Gelidiella acerosa* (Forssk) Feldm is essential to assess and determine the quality of the same. Suitable Identification and purity assessment specifications recommended by Joint FAO/WHO Expert Committee on Food Additives (JECFA) for characterization of each extracted hydrocolloid were adopted with few added counterparts. Also, general characteristics such as extraction yield, moisture, color characteristics and functional groups were screened for all the seaweed hydrocolloid, sodium alginate, carrageenan and agar extracted using different extraction methods to determine the best extraction method.

Extensive characterization of sodium alginate, carrageenan and agar from selected extraction technique were conducted using Field Emission Scanning Electron Microscope (FESEM), X-Ray Diffractometer (XRD), Thermo Gravimetric Analyser, 3D Optical profilometer and acute toxicity through Brine shrimp assay. Heavy metal safety of the extracted and selected hydrocolloids was also assessed for heavy metals such as mercury, lead, cadmium, chromium and arsenic. Microbial safety was assessed through Total Plate count method.

Phase III

i. Formulation and development of seaweed hydrocolloid films

Film forming solutions were prepared from sodium alginate, carrageenan and agar mixed in definite quantitative ratios with the addition of glycerol as plasticizer. Formulations for the film were designed based on simple centroid mixture design. Films were named accordingly from FS1 to FS10. Standardization was carried out to identify the appropriate amount of plasticizer with variations in concentration such as 0.5 ml, 1 ml, 1.5 ml accordingly. The trails done for standardizing the amount of plasticizer were named A, B, C respectively. Rheological characteristics of the film forming solutions FS1 to FS10 with variations A, B, C depending on the composition of plasticizer glycerol were analyzed with Brookfield Rheometer. Wet casting technique was adopted for the preparation of film from the formulated film forming solution.

ii. Characterization of the developed seaweed hydrocolloid films

Basic characteristics of the developed seaweed hydrocolloid films (FS1-FS10) with varying compositions of plasticizer (A, B, C) were determined through analysis of mechanical properties such as thickness, tensile strength (MPa) and percentage of elongation, moisture properties such as moisture content, Water Vapor Permeability (WVP), swelling capacity, solubility in water and Optical properties such as color. Rheological behaviors of the film forming solutions were also studied. The composition with considerable behaviors was selected for further study. Three films were selected and extensive characterization was conducted using Field Emission Scanning Electron Microscope (FESEM), Fourier Transform Infrared Spectrophotometer (FT-IR) X-Ray Diffractometer (XRD), Thermo Gravimetric Analyser and 3D Optical profilometer.

Phase IV

i. Crosslinking of the Selected Seaweed Hydrocolloid Films

Impact of crosslinking agents on the three selected hydrocolloid films were assessed with concentration and time-controlled exposure of crosslinking agents on the film surface. 2% Citric acid (X) and 2% Calcium chloride (Y) were selected as crosslinking agents in the present study with standard exposure time of 2 minutes. Peeled-off dry films were immersed in the crosslinking solution for 2 minutes and were air dried at room temperature until constant weight.

ii. Addition of fillers to the selected Film Forming Solution

In the present study Hydroxy Methyl Cellulose (C), Potato starch (S), Guar gum (G) and Whey protein (W) were selected as filler materials. Each filler compound was added in two different ratios 0.5 and 1.0 respectively into all three film forming solution mixtures. Rheological characteristics of the filler incorporated film forming solutions were analyzed with Brookfield Rheometer. Wet casting technique was adopted for the preparation of films from the formulated filler incorporated film forming solutions. Dried films were slowly peeled off from the base surface and stored.

iii. Characterization of the Crosslinked and Filler Incorporated Composite Seaweed Hydrocolloid Films

Basic characteristics of the crosslinked and filler-incorporated composite seaweed hydrocolloid films were determined through analysis of mechanical properties such as thickness, tensile strength (MPa) and percentage of elongation, moisture properties such as moisture content, Water Vapor Permeability (WVP), swelling capacity, solubility in water and optical property such as color. The organoleptic properties of the selected films were evaluated with sensory evaluation technique.

Phase V

i. Shelf Life and Feasibility Analysis of the selected seaweed hydrocolloid films

Total plate count analysis of the selected films was carried out on 1st day and 120th day. The shelf life of food products such as rice, urad dhal, salt, sugar, milk powder and chilli powder packed in the films were also assessed in terms of increase in the percentage of moisture content. A storage test was done for a period of 6 months and the gain in the moisture content of the packaged food was evaluated. Indoor soil burial degradation properties were assessed for the known quantity of films allowed for decomposition. Product feasibility was assessed through a survey questionnaire.

F. ORIGINAL CONTRIBUTIONS

Phase-I

i. Proximate nutrient content of the seaweeds

Proximate nutrient content analysis for moisture, ash, carbohydrate, protein, fat and crude fiber contents of *Sargassum cinctum* J.Agardh, *Kappaphycus alvarezii* (Doty) L.M.Liao and *Gelidiella acerosa* (Forssk) Feldm revealed the presence of 46.02 ±0.05 g,

67.82±0.06 g and 65.31±0.04 g of carbohydrate. Ash content ranged from 17.71±0.12 g, 16.30 ±0.17 g and 3.7±1.21 g. The protein content of the seaweeds were 25.23±0.03 g, 18.31±0.06 g and 15.62±0.05 g respectively. 2.19±0.10 g, 1.90±0.09 g and 2.78±0.08 g of fat and 28.24±0.05 g, 17.60±0.06 g, 11.41±0.04 g of crude fiber contents were noted. Mean moisture content ranged from 9.90±0.36 %, 16.62±0.09 % and 14.20±0.10 % respectively.

ii. Quantitative Phytochemical Analysis of Seaweeds

1. Test for phytochemical constituents in the extracts of seaweeds

Aqueous and ethanol extracts of *Sargassum cinctum* J.Agardh, *Kappaphycus alvarezii* (Doty) L.M.Liao and *Gelidiella acerosa* (Forssk) Feldm were assessed for the presence of phytochemicals such as alkaloids, carbohydrates, cardiac glycosides, flavonoids, gums and resins, phytosterol, protein and amino acid, phenol, saponin, tannin and terpenoid respectively. Qualitative analysis showed the maximum presence of carbohydrates, flavonoids, protein and saponins in the aqueous extracts of all three seaweeds.

2. FTIR Spectroscopy

Percentage of Transmittance obtained in the spectrum of Fourier Transform Infrared Spectroscopy shows corresponding wavelengths indicating the presence of several functional groups in all three seaweeds.

iii. Quantitative Antioxidant Analysis of Seaweeds

DDPH Radical scavenging activity of the aqueous extracts of the seaweeds *Sargassum cinctum* J.Agardh, *Kappaphycus alvarezii* (Doty) L.M.Liao and *Gelidiella acerosa* (Forssk) Feldm were dose-dependent. The IC 50 values were 3.832, 3.462 and 3.788 respectively wherein, the control quercetin showed 43.791.

iv. Heavy Metal content of the seaweeds

Heavy metal content of *Sargassum cinctum* J.Agardh, *Kappaphycus alvarezii* (Doty) L.M.Liao and *Gelidiella acerosa* (Forssk) Feldm for metals such as arsenic, cadmium, chromium, lead and mercury were assessed. Arsenic and lead were below the detectable limit, wherein cadmium was found to be 0.101 ppm, 0.048 ppm and 0.068 ppm respectively. Chromium was present in the level of 0.016 ppm, 0.032 ppm and 0.020 ppm and Mercury was found to be higher at the rate of 1.240 ppm, 1,033 ppm and 1.053 ppm respectively.

Phase-II

i. Characterization of the extracted seaweed hydrocolloids

1. Identification by hydrocolloid specific characteristics

Hydrocolloids were characterized using suitable identification and purity assessment specifications recommended by Joint FAO/WHO Expert Committee on Food Additives (JECFA) for all the three hydrocolloids extracted using nine extraction procedures. Sodium alginate was extracted from *Sargassum cinctum* J.Agardh using three trials such as SA1,SA2 and SA3 respectively. Carrageenan was extracted from *Kappaphycus alvarezii* (Doty) L.M.Liao using trails CA1,CA2 and CA3 . Agar was extracted using trails AG1, AG2 and AG3 from *Gelidiella acerosa* (Forssk) Feldm.

Sodium alginate SA1,SA2 and SA3 were identified for solubility, test for alginate, test for sodium, precipitate formation with calcium chloride and precipitate formation with ammonium sulphate. SA1 showed higher identification purity when compared with other trails. Carrageenan CA1, CA2 and CA3 were characterized by identification of hydrocolloid and predominant type of copolymer, solubility and test for sulfate. CA2 showed clear identification inferences compared with others. Agar AG1, AG2 and AG3 were characterized for solubility, gel formation with water, precipitate formation with ammonium sulphate solution and precipitate formation with lead acetate solution. AG2 showed clear inferences prioritizing the procedure.

2. General characterization of the extracted seaweed hydrocolloid

General characteristics such as extraction yield, moisture, optical properties and functional group through FTIR spectroscopy were assessed for all the three hydrocolloids extracted using nine extraction procedures. SA1, CA2 and AG2 showed higher purity in inferences of identification procedures as well as in FTIR spectrum and hence was chosen for bulk extraction.

3. Extensive characterization of the Hydrocolloids Extracted from selected trials- SA1,CA2,AG2

Heavy Metal Analysis showed detectable limits of arsenic and lead below the acceptable level. Wherein cadmium levels of SA1, CA2 and AG2 were 0.034ppm, 0.045ppm and 0.032 ppm. Chromium levels were 0.021 ppm, 0.060 ppm and 0.028 ppm respectively and mercury were 0.882 ppm, 0.721 ppm and 0.996 ppm. All the heavy metals were within the safer limits. **Microbiological Safety- Total Plate count** of the hydrocolloids was assessed on Day-1, Day-30 and Day-60 respectively. Maximum level of 18 $x10^1$ cfu/g for SA1, 21 $x10^1$ cfu/g for CA2 and 40 $x10^1$ cfu/g for AG2 respectively. **X-**

ray Diffraction Analysis showed that all the hydrocolloids are amorphous in nature. **Thermo Gravimetric analysis** showed the exothermic reaction of all the three hydrocolloids which charred above temperature of 100^{o}C. **3-D optical profile** provided the true color images of the hydrocolloids. **Field Emission Scanning Electron Microscope (FE-SEM)** showed the surface morphology of the hydrocolloids. **Brine shrimp lethality assay** of the hydrocolloids showed least toxicity on the viability of the brine shrimps showing the non-toxic nature.

Phase-III

i. Rheological characteristics of the developed film forming solutions

Rheological characteristics of the film forming solutions FS1 to FS10 with variations depending on the composition of plasticizer glycerol A(0.5ml), B(1.0ml), C(1.5ml) were analyzed with Brookfield Rheometer. The mean values of 10 measure points observed with Controlled Shear Rate (CSR) from 0 s^{-1} to 1000 s^{-1} for 120 seconds showed viscosity ($Pa^{-}s$) , torque(mNm), shear stress(pa) were directly related. Film forming solution with individual hydrocolloids showed maximum viscosity compared to composite mixtures. Maximum viscosity was noted in FS3C with 5.462 $Pa^{-}s$ and minimum was noted for FS8C with 0.022 $Pa^{-}s$ .Similarly torque was noted to be 16.203 mNm and 0.109 mNm. Shear stress was 2108.074 pa and 14.178 pa respectively. A slight increase in viscosity was noted with increased plasticizer concentration in most of the formulations.

ii. Characterization of the developed seaweed hydrocolloid films

1. Mechanical Properties

Mechanical properties such as thickness, tensile strength (Mpa/mm^2), tensile strain ($E=\Delta L)/L_0$) of the films FS1 to FS10 with variations depending on the composition of plasticizer glycerol A (0.5ml), B (1.0ml), C (1.5ml) were analyzed. Thickness of the films ranged from 0.0750 ± 0.005 mm to 0.3650 ± 0.463 mm. Tensile strength was found to be maximum for FS7C, FS9C and FS10A with 18.9875 ± 0.539 Mpa/mm^2, 18.7045 ± 0.891 Mpa/mm^2, 17.5689 ± 0.447 Mpa/mm^2 wherein, tensile strain was found to be maximum in all three variations of FS7 showing 0.0707 ± 0.001, 0.0793 ± 0.015 and 0.0780 ± 0.020 for A, B, C respectively indicating maximum elongation potential.

2. Moisture Properties

Moisture properties such as moisture content (%), Water Vapor Transmission Rate (WVTR) (g/h m^2), swelling capacity and solubility in water for films FS1 to FS10 with variations in glycerol composition A (0.5ml), B (1.0ml), C (1.5ml) were assessed. Moisture

content of the films ranged from 12.7400 ± 0.068 % for FS2C to 26.2613 ± 0.12800 % for FS7C respectively. Minimum Water Vapor Transmission Rates were noted for FS3A with 0.2483 ± 0.0005 and FS10A with 0.2023 ± 0.0005. Similarly, FS3B, FS5B, FS6A, FS7A, FS7C, FS9C and FS10C films also showed desirable WVTR rates. Swelling capacity of the films were directly related to the composition of carrageenan in the mixture. Films of variations FS2, FS5 and FS9 showed maximum water absorption potentials. Whereas, solubility of the films in water were directly related to the composition of sodium alginate in the mixture. Films of variation FS1 and FS4 showed 100% solubility in water. Wherein minimum solubility of 21.4643 ±0.0310 % was noted for sole agar film FS3A.

3. Optical Properties

Optical property indicates the color of the film observed in the color reader. Almost all the films exhibited lightness characteristics from 76.6267±0.341 to 85.31000±0.250 with minimum a* and b* values respectively, indicating pale yellowish films a slight red hue.

iii. Extensive characterization of the selected seaweed hydrocolloid films

Considering the mechanical and moisture properties of the developed films and on ruling out the undesired characteristics such as very less mechanical strength, complete solubleness, high water vapour transmission rates potential films can be selected. Films FS7C, FS9C and FS10A shows comparatively high mechanical strength. Also, FS7C, FS9C and FS10A shows minimum WVTR rates. On considering the merits exhibited, these three films were selected for extensive characterization.

Fourier Transform Infrared Spectroscopy results indicates the presence of functional group compounds on the fingerprint region from 400 to 1700 cm^{-1}. **Thermo Gravimetric analysis** showed exothermic reaction of all the three hydrocolloid films that charred above temperature of 100^{o}C.**3-D optical profile** provided the true color images of the selected films. **Field Emission Scanning Electron Microscope (FE-SEM)** showed the surface morphology of the films at different resolution points. **X-Ray Diffraction** graphs with little to no peak areas indicates high amorphous nature of the films.

Phase-IV

i. Rheological characteristics of the filler incorporated film forming solution

Rheological characteristics of the filler incorporated film forming solutions Hydroxy Methyl Cellulose (F7C1and F7C2), Guargum (F7G1 and F7G2), Potato Starch (F7S1 and F7S2), Whey protein (F7W1 and F7W2) for FS7C and vice versa for FS9C and FS10A were analyzed with Brookfield Rheometer. The mean values of 10 measure points observed

with Controlled Shear Rate (CSR) from 0 s^{-1} to 1000 s^{-1} for 120 seconds showed viscosity ($Pa^{-}s$), torque (mNm), shear stress (pa) were directly related. No specific relation was noted regarding the type of filler and the viscosity of composite mixtures. Maximum viscosity was noted in F10G1 with 7.965 $Pa^{-}s$ and minimum was noted for F7W1 with 0.011 $Pa^{-}s$ .Similarly torque was noted to be 23.902 mNm and 0.0.061 mNm. Shear stress was 3109.715 pa and 7.985 pa respectively.

i. Characterization of the developed seaweed hydrocolloid films

1. Mechanical Properties

Mechanical properties such as thickness, tensile strength (Mpa/mm^2), tensile strain ($E=\Delta L)/L_0$) of the filler incorporated films and crosslinked films were analyzed. Thickness of the films ranged from 0.0800 ± 0.005 mm to 0.1400 ± 0.463 mm. Tensile strength was found to be maximum for crosslinked films F7X, F9X and F10X with 2.0375 ± 0.539 Mpa/mm^2, 2.2552 ± 0.891 Mpa/mm^2, 6.8083 ± 0.447 Mpa/mm^2 wherein, tensile strain was found to be very less in all variations indicating very less elongation potentials. Fillers exhibited very little synergistic properties compared to crosslinking technique in terms of influencing mechanical characteristics.

2. Moisture Properties

Moisture properties such as moisture content (%), Water Vapor Transmission Rate (WVTR) (g/h m^2), swelling capacity and solubility in water of the filler incorporated films and crosslinked films were assessed. Moisture content of the films ranged from 12.06478 ± 0.068 % for F10Y to 24.7795 ± 0.12800 % for F7W2 respectively. Minimum water vapor transmission rates were noted for crosslinked films of variation X with 12.54451 ± 0.0005 for F7X, 9.855088 ± 0.00393 for F9X and F10X with 6.244626 ± 0.0005. Similarly, films F10W1, F10W2, F7Y, F9Y and F10Y also showed desirable WVTR rates. Swelling capacity of the films were directly influenced by the composition of carrageenan in the mixture. Films of crosslinked variations and most of the F10 variations showed minimum water absorption potentials. Whereas, all the films showed optimum solubility in water. Minimum solubility of 16.6667 ± 0.0310 % was noted for cellulose incorporated film F9C2 composition.

3. Optical Properties

Optical property indicates the color of the film observed in the color reader. Almost all the films exhibited lightness characteristics from 76.2300 ± 0.341 to 85.31000 ± 0.250 with minimum a* and b* values respectively, indicating pale yellow films a slight red hue.

ii. Sensory Evaluation

Sensory evaluation of the organoleptic properties of the selected films showed only minor fluctuations in the overall acceptability of the product. Based on the evaluation F7X scored least for flavor and taste with 7.8750±0.806 and 7.9375±0.630.

Phase-V

i. Shelf-Life Analysis

1. Microbial Safety

Total plate count analysis on day 120 showed $6x10^1$ cfu/g for FS7X, $8x10^1$ cfu/g for FS9X and $40x10^1$ cfu/g for F10X respectively.

2. Shelf life of Food Products

Shelf life assessment of the packaging material along with food products showed moisture gained over a known period of time.

ii. Indoor Soil Burial Degradation Properties

Degradation of the films was estimated based on the percentage of weight loss over a period of 30 days. Around 32 % to 35% of the total weight was decreased within a span of 15 days and about 96% to 98% of the total mass was degraded at the end of 30 days.

iii. Feasibility Analysis

Feasibility analysis of the product showed that 100% of the study participants were aware that the foods packed in plastics are harmful to their health and also, they showed their 100% support and willingness to adopt edible packaging materials in their day-to-day life if it is available in the market. But, only 77.3% of the participants were willing to pay a minimum cost for buying edible packaging materials over non-edible packaging materials considering its advantages. This creates a responsible need for producing the packing materials at a very minimal cost to attain the success of the product in the market.

G. CONCLUSION

Seaweeds collected from the study area provided hydrocolloids of very good properties. They also depicted high carbohydrate content quantitatively indicating their rich polysaccharide profile. Considering the heavy metal content, raw seaweeds were subjected to an extraction procedure that helps to extract the hydrocolloids. Characterization of the hydrocolloids gave a basic understanding of their properties and non-toxic nature.

Sodium alginate, agar and carrageenan extracted from the seaweeds had unique properties when formulated into films. Mixing these hydrocolloids with a plasticizer

provided films with different characteristics. Some advantages and disadvantages were also found in certain compositions. Considering the final application, films that exhibited high mechanical strength and low water vapor transmission rates were chosen. In order to improve the existing hydrocolloid films, crosslinking and incorporation of fillers were carried out. This attempt clearly showed that these algal hydrocolloids showed very less synergism towards non-algal polysaccharides such as Hydroxy methyl cellulose, Potato Starch, Guar gum and Whey protein in terms of improving the desired properties, especially mechanical strength. Wherein, Crosslinking treatment improved the strength to a certain extent. Shelf-life assessment on packaging essential food products such as rice, urad dhal, salt, sugar, milk powder and chilli powder with the selected films showed these packaging films could be used in day-to-day life for packing essential items of dry nature for almost 6 months without much gain in moisture content and other characteristic properties.

Feasibility analysis showed that almost everyone is concerned about well-being and health and is idealistic in showing support and willingness to adopt edible packaging materials in daily life. But real willingness depends on buying the product out from the market and paying a price considering its advantages. Feasibility analysis clearly shows that; to attain the success of the product in the market a responsible need of producing the packing materials at a very minimal cost is essential.

H. STRENGTH OF THE STUDY

1. The present study proved that the hydrocolloids extracted from seaweeds can be used for the development of food-grade packaging films.
2. Properties of the seaweed hydrocolloid films can be enhanced by controlled crosslinking treatment.
3. Hydrocolloid edible packaging films can be the replacement and one stop solution of Single Use Plastics.

I. LIMITATION OF THE STUDY

1. Only three seaweed hydrocolloids have been studied and the properties of other hydrocolloids from different species of seaweed can be studied.

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